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ENDMEMBER SELECTION PROCEDURES FOR PARTIAL SPECTRAL UNMIXING OF DAIS 7915 IMAGING SPECTROMETER DATA IN HIGHLY VEGETATED AREAS

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ABSTRACT

An intensively used agricultural test site in Switzerland is covered by the DAIS 7915 imaging spectrometer in summer 1997. Three different methods of collecting endmembers for spectral unmixing are selected and compared against each other. The methods include a soil-vegetation-atmosphere-transfer approach (SVAT) based on a leaf optical properties model (PROSPECT) and a canopy model (SAIL), image based endmember selection and in-situ reflectance measurements using a ground spectroradiometer. The presented methods are discussed and verified with an extensive ground truth. A rejection procedure for classification of unmixing results is proposed on the acceptance of constraint spectral unmixing results using the uncertainty, expressed by the RMS, of the endmember selection.

KEY WORDS: DAIS 7915, Spectral Unmixing, Hyperspectral Data, SVAT

1 INTRODUCTION

In August 1997 the Digital Airborne Imaging Spectrometer (DAIS 7915) operated by DLR (German Aerospace Research Establishment) has been flown over an intensively cultivated agricultural area, the Limpach Valley (470 m a.s.l.) located in Western Switzerland. The area covered by the DAIS is 2.5 x 10 km and consists mainly of crops, meadows and sugar beet.

The DAIS-7915 is a 79-channel high-resolution optical spectrometer that covers the wavelength-range between 0.5 μm and 12 μm using a Kennedy type scanning mechanism. The first 72 channels cover the reflective part of the electromagnetic spectrum whereas the channels 73-79 are located in the MIR and TIR range. The DAIS is operated aboard DLR's Dornier DO228 aircraft and has a swath angle of 52°, subdivided into 512 pixels per scanline [1]. The flight altitude was approximately 3840 m a.s.l, resulting in a ground sampling distance of 5.5 m in line direction. The flightline is recorded using a differential GPS on board of the DO228 and on preselected ground control points [2].

Numerous spectroradiometric measurements on selected reference targets have been taken in the test area using a GER-3700 spectroradiometer. This 704 channel spectroradiometer is located in the 0.4 μm - 2.5 μm wavelength range. The GER-3700 is calibrated in the laboratory by RSL [3].

Mapping of the land cover and determination of the field borders is based on aerial photography. This allows for assessing the quality of the spectral unmixing results. More than 90 fields with their land cover can therefore be identified on the DAIS image.

2 METHODOLOGY

The DAIS 7915 data are provided as radiance-calibrated data from DLR Oberpfaffenhofen. The preprocessing of the imaging spectrometer data includes an MNF (Minimum Noise Fraction) transformation. The conversion to apparent reflectances is performed using an atmospheric correction program (ATCOR-2) [4]. Since no in-situ meteorological data is available for the time of the datatake, the horizontal visibility is determined using a comparison of different modelling approaches with in-situ reference spectra. This procedure is carried out iteratively, based on IFCALI [4]. The correction procedure strongly overestimates the water vapor due to laboratory calibration errors of the DAIS imaging data resulting in an overcorrection in the 940 nm water vapor absorption band [5].

The spectral library concept in general is based on the spectral variability of the selected endmembers. The dimensionality of the endmembers is determined in a four step approach: The measurement noise of the data is determined using MNF transforms. Non-linear effects like multiple scattering and transmittance through optically thin endmember layers of vegetation are not modeled and therefore act as unmodeled bias terms. To avoid a large number of endmembers in small proportions, the target area for spectral unmixing is reduced by assuming four major types of linear contributing endmembers such as the dry biomass (ripe wheat), soil, shade and vegetation (grass and sugar beet). Since large variations in the endmember spectra can contribute to low spectral contrast and limit the useful dimensionality of the data, endmembers should result from homogeneous data sources such as large homogeneous fields, especially if they are selected from imaging data [6].

Because of noisy SWIR bands of the DAIS and the importance of specific vegetation related absorption bands [7] (e.g. chlorophyll a and b, water absorption) and the position of the red-edge, the analysis focuses on the first 40 channels of the DAIS, covering the 0.5 µm - 1.8 µm . Major attention is given to agricultural land, so that the abovementioned four types of linear contributing endmembers are assumed to be present in the area under investigation in a statistically significant amount. The three different approaches for the endmember collection applied are:

- image based selection using the inner part of a field
- spectroradiometric measurements of reference targets
- SVAT modelling of endmember spectra

Image based selection: Endmembers are selected within the inner part of a field to avoid the selection of adjacency influenced border pixels. Shadow, that has a signal close to 0, because atmospherically corrected ground reflectance data contain no path scattered radiance, is introduced. Adjacency and directional effects in the shadow are assumed to be close to 0, too.

Spectroradiometric measurements of reference targets: Measurements of reference fields (e.g. grass, sugar beet and ripe wheat) are convolved to the required wavelength of the DAIS 7915 channels.

Modelling endmember spectra: Endmembers of green vegetation (grass and sugar beet) are modeled using a SVAT approach. In order to simulate canopy reflectance, a single leaf reflectance model (PROSPECT [8]) and a canopy reflectance model (SAIL [9]) are combined.

PROSPECT uses as input a leaf mesophyll structure parameter N, chlorophyll content, leaf dry mass and leaf water content. It simulates leaf reflectance and leaf transmittance between 0.4 μm and 2.5 μm as a function of the abovementioned leaf optical properties. The output of the PROSPECT model is then used as input to the SAIL model. The SAIL model uses as input canopy variables (e.g. leaf area index, leaf angle distribution, leaf reflectance and transmittance), soil reflectance, the ratio between diffuse and direct irradiance and solar/view geometry (solar zenith angle, zenith view angle and relative angle between sun and view azimuth [10]. The PROSPECT parameters are calculated by inverting an averaged measured high resolution spectrum of vegetation (grass and sugar beet) and by minimizing the RMS-error between modeled and measured spectra. The SAIL model calculates canopy reflectance under different view zenith angles which become important when performing comparisons with sensors having a large scan angle such as the DAIS. Canopy reflectance depends on the sensor's changing view zenith angle and the changing relative azimuth angle between sun and viewing direction. Since the main area of interest is completely flat and lies within 13° to each side from nadir view, only nadir-modeled spectra are used for the modelling approach. However, Fig. 1 and Fig. 2 show the variation in canopy reflectance of grass and sugar beet resulting from changing view zenith angles. Since soil and dry biomass (ripe wheat) do not represent vital vegetation, these endmembers are not modeled, but substituted by the field reflectance measurements. Fig. 1, Fig. 2 and Fig. 3 show the endmember spectra for grass, sugar beet, wheat and soil.

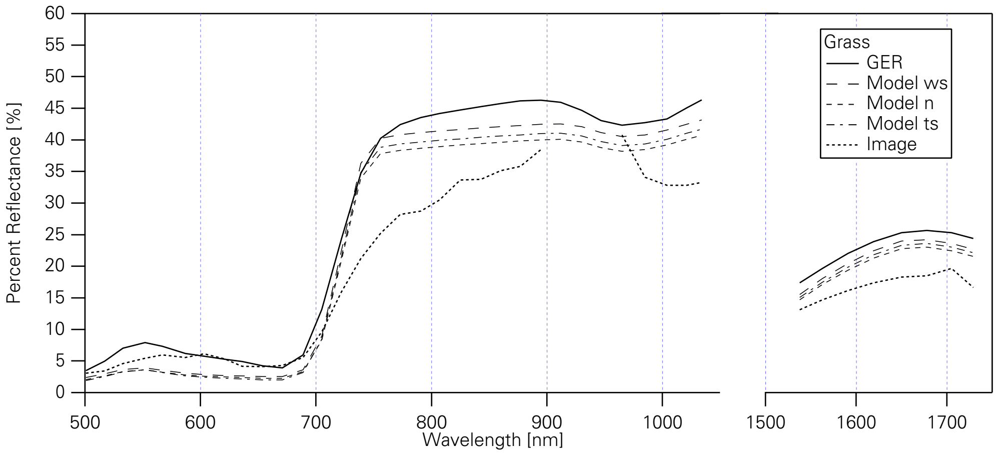

FIGURE 1: Measured, image derived and modeled endmember spectra for grass (ws: looking with the sun $\Delta\varphi = 45°$), n: nadir view, ts: towards the sun $\Delta\varphi = 45°$

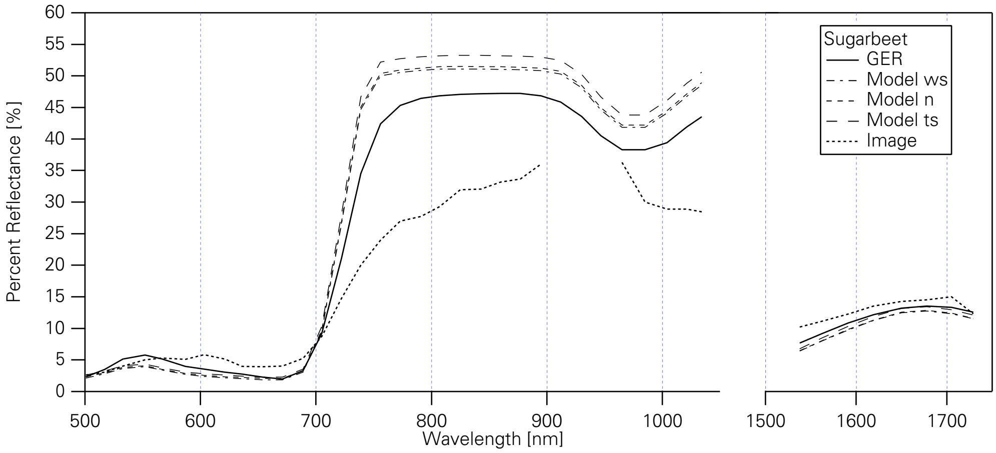

FIGURE 2: Measured, image derived and modeled endmember spectra for sugar beet (ws: looking with the sun $\Delta\varphi = 45°$), n: nadir view, ts: towards the sun $\Delta\varphi = 45°$

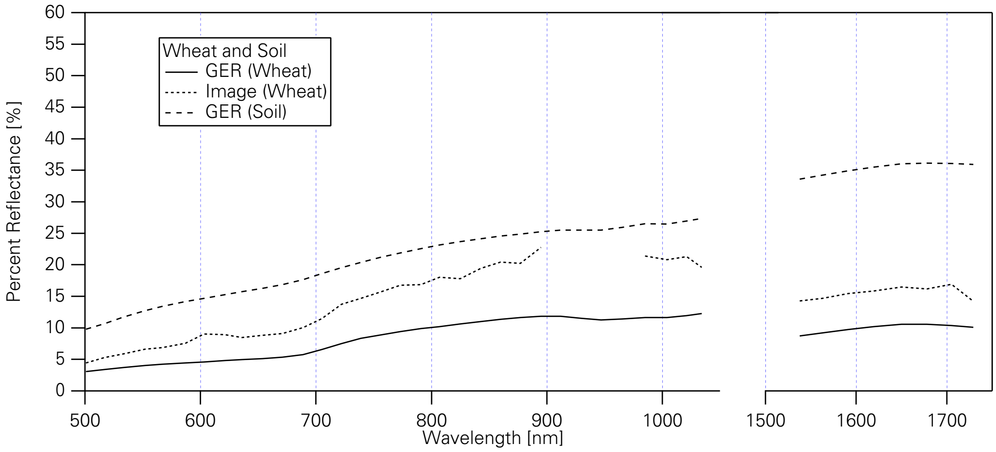

FIGURE 3: Measured and image derived endmember spectra for dry wheat and measured endmember spectrum for soil

The evaluation of the different results of these three approaches of endmember selection for spectral unmixing are discussed focussing on well defined verification areas of sugar beet. Sugar beet is one of the predominant land cover in the observed area. Abundance maps of the sugar beet endmember are generated in a two step approach: First, based on the resulting RMS (root mean square error) of the spectral unmixing procedure, which is calculated for each pixel, areas having an RMS larger than ($RMS_{mean}+2\delta(RMS)$) were excluded from further interpretation. Large RMS values indicate poor unmixing results based on the selected endmembers. Second, endmember abundances lower than zero are also excluded.

Since in-field variation can decrease the purity of an endmember group, an iterative application of this procedure can be used to obtain purer endmember spectra, especially in the case where they are derived from regions of interest of the imaging data. Fig. 4 clearly shows the inhomogenities of the sugar beet field used for the collection of the sugar beet endmember.

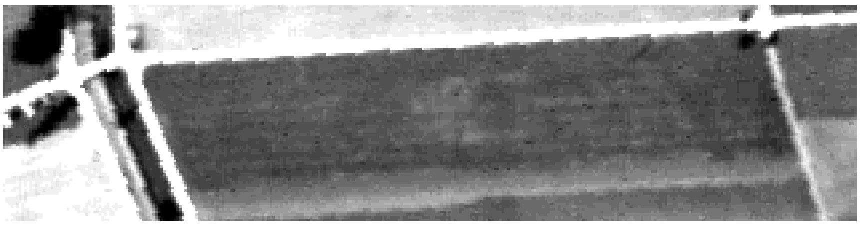

FIGURE 4: In-field variation of the sugar beet endmember field as seen by the simultaneously flown WAAC (Wide Angle Airborne Camera)

The abundance maps of sugar beet are geocoded using a parametric geocoding approach (PARGE) including a DEM (Digital Elevation Model) and the attitude data of the aircraft [11].

3 RESULTS AND CONCLUSIONS

Spectral mixture analysis is based on the assumption that most of the spectral variation within imaging data is caused by mixtures of a limited number of surface materials. Linear spectral unmixing assumes no interaction between materials and therefore models the observed spectral reflectance as linear combinations of pure endmembers [12]. In this work, a weighted constrained linear unmixing is applied, allowing abundances to have values lower than 0 or greater than 1, but summing up to unity [13]. As pointed out by Schanzer [14], abundances can take on values greater than 1 or lower than 0. If the response of a pixel is purer than the selected endmembers, endmember abundances greater than 1 and lower than 0 will occur.

Fig. 4 shows a geometrically corrected subset of the three unmixing results. The results from image based endmember selection (left), measured endmember spectra (middle) and modeled endmembers (right) are compared to each other focussing on sugar beet. Differences of abundances of the sugar beet endmember on the same fields are obvious for the three approaches.

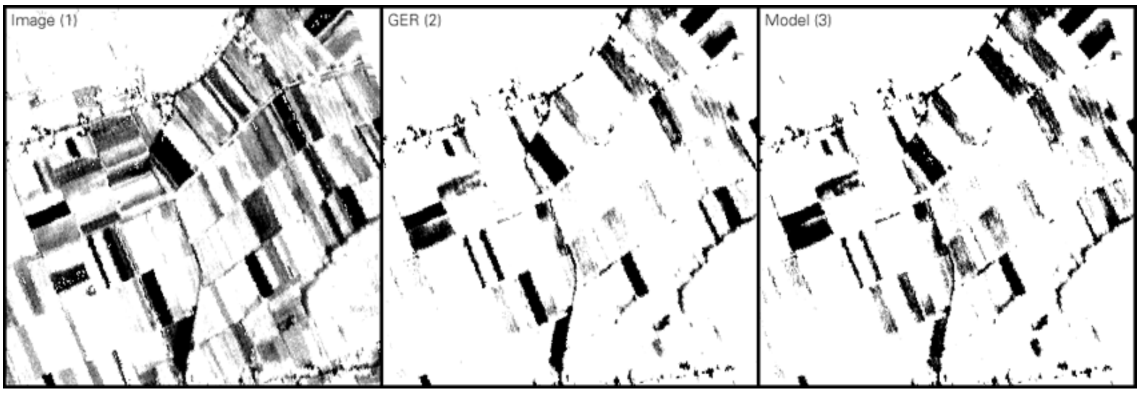

FIGURE 5: Abundance maps of sugar beet from image derived (1), in-situ measured (2) and modeled (3) endmember spectra

Image derived endmembers tend to be less pure than measured or modeled endmembers, since they are composed of a mixture of the observed vegetation as well as soil and shade present in the target area. Measuring endmember spectra focussing on the vegetated part itself or modelling them from biochemical, biophysical and geometrical parameters leads to purer spectra of the desired endmember. This fact can be seen in the three images very well. The image based approach (1) shows many fields with some amount of sugar beet abundance whereas no or less abundance of this endmember can be found in the same fields in the measured (2) and modeled (3) endmember approaches. Dark fields are sugar beet plantations. They show highest abundances of sugar beet for all three approaches, although the abundance values differ significantly. Pixels as pure as the measured and modeled endmembers are hardly any found in the image.

The scene based approach instead bases on impure endmembers. The field where the endmembers for sugar beet are collected (see Fig. 4) is obviously a mixture of various contributing species like soil, shade, weed and sugar beet. Therefore, evaluation fields with a higher amount of sugar beet lead to a purer response than the endmember itself. This is the case of feasible endmember collection [14]. Abundance values greater than 1 occur. This forces parts of the remaining endmembers to become negative.

To solve this problem, an iterative approach of scene based endmember collection is applied to the data. A first unmixing result allows identification of purer endmembers than the initial ones. Based on the resulting RMS of this first spectral unmixing procedure, pixels of the verification area that have an RMS larger than ($RMS_{mean}+2\delta(RMS)$) are excluded. Values lower than 0 are excluded as well. These endmembers are used in a second unmixing step. This process can be repeated until a certain "purity-criteria" like no negative abundances or all abundances between 0 and 1 is achieved. Fig. 6 shows the differences between a one-step spectral unmixing of sugar beet and a two-step unmixing based on iteratively determined purer endmembers from imaging data.

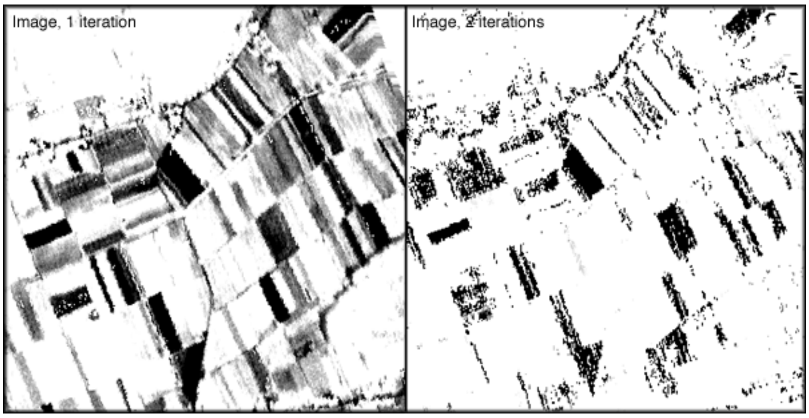

FIGURE 6: One-step (left) and two-step (right) spectral unmixing of sugar beet, based on image derived endmembers

The evaluated methods indicate that ground truth collection is important to validate the different approaches of endmember selection. Correlating field measurements of biochemical and biophysical parameters to imaging data can offer the possibility to retrieve such parameters from imaging data. The approach using in-situ reference measurements of endmember spectra and the modelling approach using a SVAT Model may be more promising since image derived endmembers are made up of a spectral mixture of contributing elements, unless pure pixels are iteratively determined.

Nevertheless, it remains difficult to define representative endmember spectra. Modelling endmember spectra bases on the availability of a range of parameters describing the status of the plant and the architecture of the canopy, which itself is subject to strong BRDF effects. Applications in vegetation studies have to take into account these effects, since airborne imaging spectrometers with large swath angles produce data of high geometric complexity.

4 REFERENCES

[1] OERTEL, D., 1994: "The High Resolution Imaging Spectrometer DAIS: a Status Report", in: 2nd EARSEC Status Seminar, ed. A.J. Sieber, JRC Ispra

[2] SCHAEPMAN, M., KNEUBUEHLER, M., MEIER, E., MUELLER,SCHLÄPFER, D., STROBL, P., REULKE, R. AND HORN, R., 1998: "Fusion of Hyperspectral (DAIS 7915), Wide-angle (WAAC), and SAR (E-SAR) Data Acquisition Methods - The MultiSwiss'97 Campaign", Proc. SPIE, 3438

[3] SCHAEPMAN, M., 1998: "Calibration of a Field Spectroradiometer - Calibration and Characterization of a Non-Imaging Field Spectroradiometer Supporting Imaging Spectrometer Validation and Hyperspectral Sensor Modelling", PhD thesis, Dept. of Geography, Univ. of Zurich, p.146

[4] RICHTER, R., 1996: "Atmospheric correction of DAIS hyperspectral image data", Computers and Geosciences, 22: 785-793

[5] SCHLÄPFER, D.R., 1998: "Differential Absorption Methodology for Imaging Spectroscopy of Atmospheric Water Vapor", PhD thesis, Dept. of Geography, Univ. of Zurich, p. 131

[6] ENDSLEY, N. H., 1995: "Spectral unmixing algorithms based on statistical models", Proc. SPIE, 2480: 23-36

[7] VERDEBOUT, J., JACQUEMOUD, S. AND SCHMUCK, G., 1994: "Optical properties of leaves: modelling and experimental studies", in: Imaging Spectroscopy - a Tool for Environmental Obs., eds. Hill, J. and Mégier, J., Euro Courses, Kluwer, 4: 169-191

[8] JACQUEMOUD, S. AND BARET, F.,1990: "PROSPECT: a model of leaf optical properties spectra", Rem. Sens. Env. 34: 75-91

[9] VERHOEF, W., 1984: "Light scattering by leaf layers with application to canopy reflectance modelling: the SAIL model", Rem. Sens. Env. 16: 125-141

[10] CLEVERS, J.G.P.W., 1994: "Imaging spectrometry in agriculture - plant vitality and yield indicators", in: Imaging Spectroscopy - a Tool for Environmental Obs., eds. Hill, J. and Mégier, J., Euro Courses, Kluwer, 4: 193-219

[11] SCHLÄPFER, D., MEYER P. AND ITTEN, K.I., 1998: "Parametric Geocoding of AVIRIS Data Using a Ground Control Point Derived Flightpath", Summaries of the Seventh JPL Airborne Earth Science Workshop, (in press), JPL, Pasadena (CA), pp. 6

[12] BOARDMAN, J.W., 1990: "Inversion of high spectral resolution data", Proc. SPIE, 1298: 222-233

[13] RSI Inc., 1997: "ENVI User's Manual", Vers. 3.0, Lafayette

[14] SCHANZER, D.L., 1993: "Comments on 'The Least Squares Mixing Models to Generate Fraction Images Derived for Remote Sensing Multispectral Data'", TGARS, 31: 747